Retrofitting of Masonry Buildings by Base Isolation

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***Abstract*- Seismic response of masonry buildings retrofitted using base isolation technique is investigated. The concept of seismic isolation is applied here by separating the super structure from the foundation at plinth level by a sliding earthquake energy reducing friction layer in the form of green marble/geosynthetic. The dynamic interface property of the sliding couple has been investigated. In order to investigate the effectiveness of base isolation the response of the sliding system is obtained numerically by solving the governing equations of motion under under synthetically generated IS: 1893, 2002, spectrum compatible accelerogram corresponding to most severe seismic zone of India (PGA=0.36g) and compared with the corresponding fixed base structure. It is observed that 50% reduction in maximum roof acceleration for the base isolated structure in comparison to the maximum roof acceleration of conventional structures limiting the earthquake energy transmission to super structure during strong earthquake, leading lesser damage of masonry buildings in earthquake prone area and can be used as a low cost base isolation for earthquake hazard mitigation**

***Index Terms*- Earthquake hazard mitigation, masonry buildings, Geosynthetic, Pure friction base isolation**

I. Introduction

Masonry construction is the most popular and suitable for low cost housing purposes in almost all developing countries. These buildings are seldom designed against earthquake forces and are prone to collapse during earthquake. Retrofitting is one of the emerging technologies to overcome these deficit buildings to make them strong enough to mitigate the impact of earthquake hazards. Base isolation is one of the retrofitting techniques used widely over last 4-5 decades. Out of several base isolation devices the pure friction (P-F) base isolation system is the simplest and is ideally suited for use in low-cost masonry buildings. Attempt has made to apply a sliding earthquake energy reducing friction layer in the form of green marble/ geosynthetic sliding couples which are easily available in the Indian market cheaply and can be easily bonded to building materials has been placed at the plinth level as shown in Fig.1.

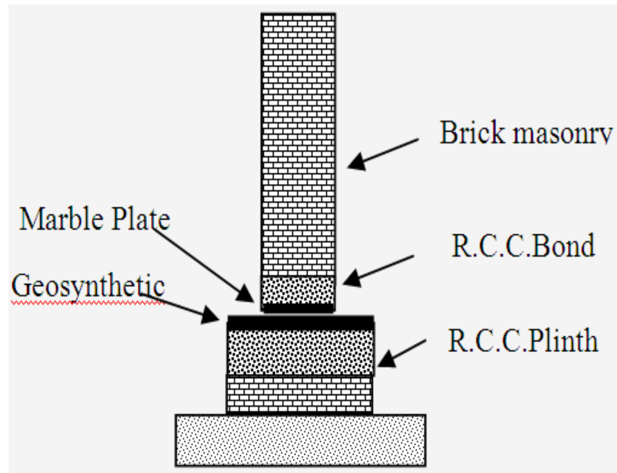

Figure 1. Construction detail for P-F isolation system in brick wall of a brick masonry building

The main concept of base isolation consists of decoupling the super structure at its base i.e. plinth level from the damaging effect of horizontal component of induced ground motion. To achieve this, a smooth layer is introduced at plinth level, on which the super structure simply rests and is free to slide except for friction resistance. Thus, leading to mechanisms such as:

- Friction allowing some parts to slide relative to other.
- There is a limitation of transfer of seismic input energy to structure.
- Energy dissipation takes place due to coulomb friction

Arya[1] Qamaruddin et al. [4], proposed a *sliding joint* concept which consists of decoupling the building at the plinth level, by providing a smooth finished layer of cement sand mortar above which mobil oil was applied. Feasibility study of this concept had been tested sliding brick building models with different sliding layer materials, namely, graphite powder, dry sand, and wet sand.The cracking observed in sliding specimens had been much less than in conventionally strengthened specimens. A similar P-F isolation system had been proposed by Chinese group (Li [3]) with specially screened sand layer in between terrazzo plate. The effectiveness of isolation system was tested by shake table test. It was confirmed that the sliding begins when input acceleration exceeds a certain level, depending upon the coefficient of friction value of the sliding layer. Lou et al. [7] have experimented with low friction materials as sliding joints to ensure building safety during strong earthquakes. Several brick with and without sliding joint were tested under lateral loads with simulated dead load. The walls with sliding joints

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were observed to slide at a lateral force amplitude 50% of the lateral force at which cracking begins in wall without sliding joint.The effectiveness of non-woven geotextile-smooth marble sliding interface as a frictional base isolation system for masonry building was studied by nanda et al. [5] with the help of experimental and analytical studies. During simulated earthquake tests on shake table, a 65% reduction in the maximum acceleration response at the roof level of building on sliding base was observed in comparison with the response of a similar fixed base building.

It had been observed that response of structure by P-F system strongly dependent upon friction coefficient of the sliding couple. The lower the friction coefficient lower is response acceleration and the base shear force. There is no restoring force provided by any type of external horizontal spring or damping elements. Lack of additional damping element causes sliding displacement at isolation levels. Special attention has to be considered to keep these displacements within manageable limits However lower frictional coefficient leads to larger sliding displacement. So a usable coefficient value has been empirically stated from 0.05 to 0.15 (Nikolic-Brzev [6]). The sliding materials should be, durable, economically available and can be constructed without any complication. Previous investigations reveals that Teflon (PTFE) sliding against stainless steel gives very low friction value in the most desirable range ie.0.05 to 0.15. For this reason Teflon has been utilized widely for more than 30 years in seismic isolator for bridges.

However, bonding steel sheets continuously over concrete course is very much expensive and leads to construction complication. Graphite, grease, screened sand, dry and weight sand (see, e.g., Arya [1], Li [3], Lou et al. [7]), are good alternate but they cannot be used for a long term as grease can be contaminated by debris, dirt etc., graphite can be affected by chemical and sand gets crushed after the shock which will increase the frictional characteristics. Thus there is a need for search for alternate interface materials which may be easily available, economically viable and can be used with lesser complications. The dynamic interface properties of these materials are being investigated and used in mathematical model for obtaining the seismic response of single story masonry buildings.

II. Analytical Modelling

The building is idealized as two degree of freedom discrete lumped mass model. The spring (K) and damping action (C) in the system is assumed to be provided by the wall elements. The mass of the roof and one half height of the wall is lumped at the top (M_t) while the remaining half of the wall and the bond beam mass is lumped at base (M_b). The lower mass is assumed to rest on a plane with dry frictional damping to permit sliding of the system. Let the ground acceleration be denoted by $\ddot{x}_g$; x_t and x_b represent the relative displacement of top mass with respect to bottom mass and relative displacement of the bottom mass with respect to ground respectively.

The building material is assumed to be elastic. Its stiffness is computed by considering bending as well as shear deformation in the wall elements. It is assumed that the sliding displacement between the contact surfaces can occur without overturning or tilting.

A. Non sliding:

$$M_t(\ddot{x}_g + \ddot{x}_t) + C\dot{x}_t + Kx_t = 0$$

B. Sliding:

Top mass-

$$M_t(\ddot{x}_g + \ddot{x}_b + \ddot{x}_t) + C\dot{x}_t + Kx_t = 0$$

Bottom mass-

$$M_b(\ddot{x}_g + \ddot{x}_b) - C\dot{x}_t - Kx_t + \mu(M_t + M_b)g\ \mathrm{sgn}(\dot{x}_b) = 0$$

Where sgn () is the signum function defined by

$$\mathrm{sgn}(x) = \begin{cases} 1, & x > 0 \\ -1, & x < 0 \end{cases}$$

And θ= M_t/ M_b, is the mass ratio (MR) and μ, is the coefficient of static friction which is assumed to remain constant during entire excitation period.

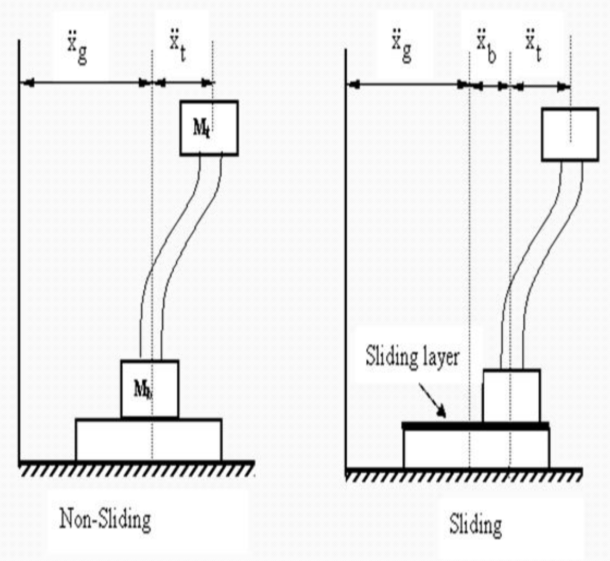

Figure 2. Mathematical model.

The non sliding conditioned is determined when the horizontal inertia force does not exceed the opposing friction force, i.e.

$$\left|C\dot{x}_t + Kx_t - M_b(\ddot{x}_g + \ddot{x}_b)\right| < \mu(M_t + M_b)g$$

As long as the force, that causes sliding exceeds the frictional resistance the bottom mass moves with the base and the system acts as a single degree of freedom system. As soon as the force acting at the base exceeds the maximum static friction bottom mass begins to slide and after sliding begins it can cease at any instant of time when non slip condition reached. Hence at any instant response of the building can be obtained by solving the two simultaneous

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equations for sliding case with the non slip condition. These equations are solved by MATLAB 7.0.1 SIMULINK environment with ODE4 Rungekutta solver

III. Friction Test

The experimental set up was as shown in Fig. 3. It consists of the following components. A mild steel foundation plate was anchored to the ground by foundation bolts. The foundation plate was provided in order to provide support to the shear box. The shear box was kept in between two plates, namely the bottom plate and the top plate (200mm diameter and 20mm thick). The lower half of the shear box of 50mm height was kept over the bottom plate. When a horizontal load was applied, the bottom plate moved and thus created shear deformations along the predetermined shear surface i.e. mid height of the sample. The normal load was applied through this assembly that consists of a hydraulic jack and a reaction beam. In order to apply a shear load, an actuator was used and this was fixed to the bottom plate of the shear box. The upper half of the shear box was restrained horizontally, using a beam column arrangement, such that it does not move when the horizontal load was applied. The large shear box is circular in shape was designed to accommodate samples of 314.15 square centimeter cross sectional size i.e. sample of 20 cm diameter.

Figure 3. Experimental set up for servo controlled actuator and sliding samples.

The specimens of 20 cm diameter and 5 cm height concrete (1:1.5:3 ratio) casted with ground polished smooth green marble on one side. With some specimens, 2 mm thick Geosynthetic sheet Polyfelt.TS-50 is pasted by Bond Tite adhesive. Static tests were planned under strain controlled conditions. The ramp rate was kept constant at 0.5mm/sec and the normal load was from 10 kN to 50 kN. Ramp limit was fixed as 25mm. Load and displacement data was obtained from the load cell and displacement transducer embedded in the actuator system.The load displacement graph is shown in Fig.4. The coefficient of static friction from the static test was obtained as the ratio of the maximum shear force just before sliding to the normal load. No significant variation was observed in the coefficient of static friction for the range of normal loads considered. From these tests, the average value of coefficient of static friction was obtained as 0.11.

IV. Results And Discussion

From the friction test the coefficient of friction between the proposed interfaces lies in the desirable range i.e. 0.05 to 0.15.The above friction coefficients has been used in the analytical model. The effect of the ground motion on the behaviour of geosynthetic/marble isolation system is investigated analytically by using a synthetic accelerogram that is compatible with the design spectrum of IS 1893 (Part 1): 2002 corresponding to the level of maximum considered earthquake in the most severe seismic zone (PGA=0.36g). Fig.5 represents the ground motion and comparative absolute acceleration and displacement response for fixed and sliding single story building of mass ratio (MR) =2, time period 2 sec and damping 5% critical. In case of fixed building there is acceleration amplification as compare to ground motion. The peak absolute acceleration at roof level is 0.8g while 0.4g for base isolated sliding interfaces i.e. 50% reduction in roof acceleration.

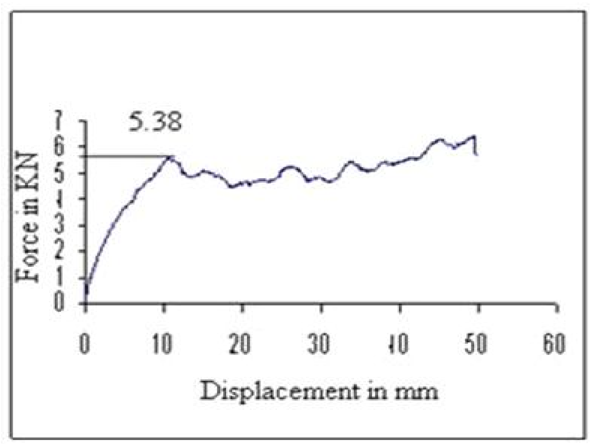

Figure 4. Graphs showing static friction test

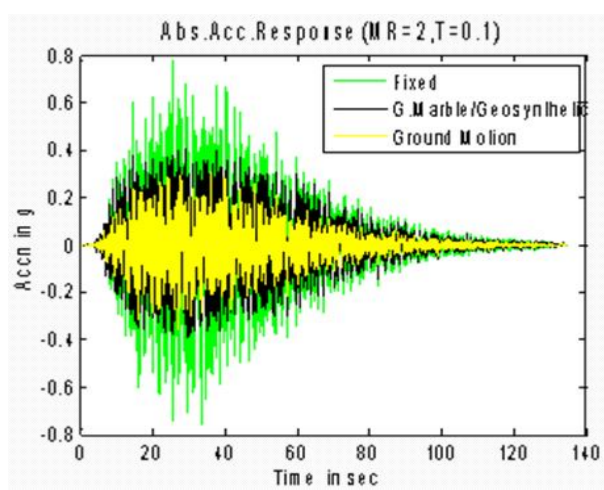

Figure 5. Absolute acceleration response at roof level for sliding and fixed model

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From relative displacement response for sliding and fixed single story building of mass ratio (MR) =2, time period 2 sec and damping 5% critical, (Fig.6) it is found that the maximum relative sliding displacement is 20 mm which is well within commonly applied plinth projection of 75mm.

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